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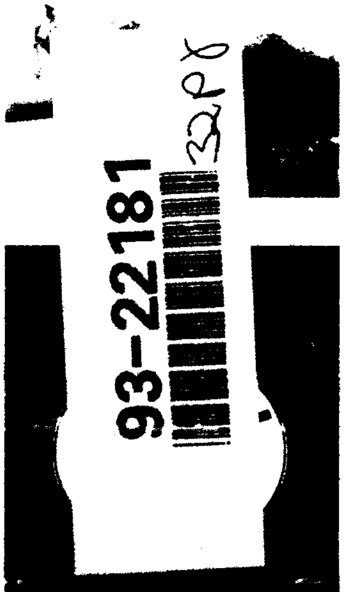

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TRENDS IN PCB CONTAMINATION IN FISHES FROM WISCONSIN WATERS OF LAKE MICHIGAN, 1978-1986

by

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13. ABSTRACT *(Maximum 200 words)*

Data from 1,969 samples of 36 fish species collected from Wisconsin waters of Lake Michigan were examined to determine trends in polychlorinated biphenyl (PCB) contamination from 1978 through 1986, and to assess ambient PCB body burdens in 13 selected species, primarily sport fishes. PCB levels were generally higher in fishes collected in coastal waters compared with fishes collected in offshore waters, and in fishes from southern Green Bay compared with those from northern Green Bay. Body burdens in all regions and most species have declined over the time period, with dramatic declines since 1978 in northern pike (*Esox lucius*), walleye (*Stizostedion vitreum*), and carp (*Cyprinus carpio*) from coastal waters. By 1986, mean PCB levels in most species had declined below the U.S. Food and Drug Administration action level of 2 µg/g wet weight; exceptions included channel catfish (*Ictalurus punctatus*), chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), and walleye. PCB concentrations tended to increase with fish weight, length, and percent lipid, although strong correlations were rarely noted. Highest mean PCB concentrations occurred in some top predators and some bottom-feeding species, suggesting that food chain biomagnification and partitioning from contaminated sediments may both be important mechanisms for PCB bioaccumulation in Lake

(Continued)

14. SUBJECT TERMS

Bioaccumulation	Percent lipid	Regional trends
Fish	Polychlorinated	Sample type
Lake Michigan	biphenyls (PCBs)	Temporal trends

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Michigan fishes. PCB levels were significantly higher in whole fish samples than in fillets in only 6 of the 13 species considered; lipid content was significantly higher in whole fish than in fillets in 4 of those 6 species. This study and other analyses based on total PCBs can assess degree of contamination, but are limited by their inability to determine presence or quantity of the relatively few potentially toxic PCB congeners.

Contents

Preface

The research on which this paper is based was conducted by the U.S. Army Engineer Waterways Experiment Station (WES), Environmental Laboratory (EL), Vicksburg, MS. Funding was provided by the Dredging Operations Technical Support Program, and by the U.S. Army Engineer District, Chicago, through an Intra-Army Order for Reimbursable Services.

Authors of this paper were Ms. Joan U. Clarke of the Aquatic Contaminants Team, Contaminant Mobility and Regulatory Criteria Group (CMRCG), Ecosystem Research and Simulation Division (ERSD), EL; and Messrs. Paul L. Whitman and John Dorkin, Environmental and Social Analysis Branch (ESAB), Planning Division (PD), Chicago District.

The study was conducted under the general supervision of Dr. Lloyd H. Saunders, Chief, CMRCG, and Dr. Bobby L. Folsom, Jr., Acting Chief, CMRCG; Ms. Barbara Williams, Chief, ESAB; Mr. Donald L. Robey, Chief, ERSD; and Mr. Phillip Bernstein, Chief, PD. Chief of EL was Dr. John Harrison.

Data and/or information on laboratory analysis techniques were provided by the following individuals and agencies: Bruce Baker, Robert Masnado, and Lee Liebenstein, Wisconsin Department of Natural Resources (WDNR); Jack Daulbert, Wisconsin Department of Agriculture Laboratory; and David Degenhardt, Wisconsin State Laboratory of Hygiene. Technical review of this paper was provided by Lee Liebenstein, WDNR; Jan Miller, U.S. Army Engineer Division, North Central; and Victor McFarland and Douglas Clarke, WES. The authors are also grateful to John E. Gannon and Robert Hesselberg, U.S. Fish and Wildlife Service, and D. Michael Whittle, Canada Department of Fisheries and Oceans, for helpful comments on the manuscript.

Dr. Robert W. Whalin was Director of WES. COL Leonard G. Hassell, EN, was Commander and Deputy Director. LTC Randall Inouye was Commander and District Engineer of Chicago District.

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1 Introduction

Polychlorinated biphenyls (PCBs) have been identified as environmental contaminants of concern throughout the Great Lakes, especially near major urban and industrial areas, as well as areas of high particulate deposition far from point sources (Swackhamer and Armstrong 1986). PCBs are persistent organic contaminants known to bioaccumulate in aquatic organisms with potentially toxic consequences (Gruger et al. 1975; Mauck, Mehrle, and Mayer 1978; Spies, Felton, and Dillard 1982; Fries and Lee 1984; Spies et al. 1985; Lee 1988; McFarland and Clarke 1989; Weis and Weis 1989). Human health risks may result from consumption of PCB-contaminated food. A major human food source of PCBs is fish taken from certain areas of the Great Lakes and other bodies of water that have experienced considerable contaminant input from industrial and other sources.

PCBs enter and move through the aquatic environment via a variety of pathways, including water, air, precipitation, sediment, and food. Fine-particle sediments (i.e., clays and silts) on river and lake bottoms, especially those sediments that are rich in organic matter, can be a major source of PCBs to aquatic organisms, as well as a net PCB sink. Sediments near major urban and industrial centers are particularly susceptible to PCB contamination.

Federal navigation channels and harbors are often associated with major urban and industrial centers within the Great Lakes region. The U.S. Army Corps of Engineers is responsible for the operation and maintenance of such facilities and must periodically dredge and dispose of bottom sediments that accumulate from upstream soil and bank erosion. Due to the contaminated nature of some of these sediments, dredging and disposal activities have generated concern over the potential for increased bioaccumulation of contaminants by aquatic organisms. Currently, environmental laws and regulations require that contaminated dredged materials be disposed in confined disposal facilities and that the environmental impacts of these activities be fully addressed. To date, many confined disposal facilities have been constructed around the Great Lakes region; most of these are in-lake facilities.

As part of the environmental impact assessment process mandated by the National Environmental Policy Act for proposed federal actions (such as dredging and disposal activities), the U.S. Army Corps of Engineer District, Chicago, began examining PCB bioaccumulation potential from sediment sources. Before bioaccumulation impacts of dredging and disposal activities within the Lake Michigan basin could be fully assessed, an extensive body-burden baseline study was deemed necessary. The baseline data would then later be compared to data collected after dredging and disposal activities at various locations around Lake Michigan, and bioaccumulation impacts could then be determined. Such baseline data for PCBs in fish tissues were already available from existing literature and ongoing state and federal monitoring programs throughout the Lake Michigan basin, beginning in 1970. Therefore, new data were not collected, but rather the existing data were utilized to determine regional and species trends over time for PCB contamination of fishes from Lake Michigan.

2 Materials and Methods

Existing data were initially gathered from a wide variety of sources including the STORET computerized data system of the U.S. Environmental Protection Agency, several state computerized contaminant databases, and literature (Schacht 1974; Zabik, Olson, and Johnson 1978; Sheffy and Aten 1979; Rohrer, Forney, and Hartig 1982; Schmitt et al. 1983; DeVault and Weishaar 1983, 1984; DeVault 1985; DeVault, Willford, and Hesselberg 1985; DeVault et al. 1988; Hazelton Laboratories America, Inc. 1986; Masnado 1987; Chicago Department of Public Health data in Meunch 1981). Approximately 4,000 samples, collected from locations throughout the Lake Michigan basin between 1970 and 1986, were compiled. Over 20 agencies and laboratories were involved in sample collection and analyses during that time. Unfortunately, not all of the laboratories used the same or even comparable PCB analytical techniques. In many instances, quality control programs had not been implemented until recently, if at all. In addition, contaminant analysis methodologies and technologies changed or improved over the years. Furthermore, a uniform standard Aroclor mixture was not used for PCB quantitation by the various laboratories. All of these factors indicated that there could be a severe comparability and reliability problem with the data contained in this large data set, thereby potentially invalidating any conclusions drawn from statistical analyses of the data set.

After a series of discussions with many laboratory personnel, we determined that the PCB analyses of fishes from the Wisconsin waters of Lake Michigan (collected primarily by the Wisconsin Department of Natural Resources (WDNR) and analyzed by the Wisconsin State Laboratory of Hygiene (WSLH)) for the years 1978 to 1986 were the most consistent and reliable, as the WSLH analytical techniques remained virtually unchanged during this time. The results described in this paper are restricted to this portion of the data set, which includes 1,969 samples representing 36 fish species.

Sample Collection and Analysis

The majority of samples from Wisconsin waters of Lake Michigan were collected by WDNR personnel using trap nets, gill nets, and electroshocking, although most samples in 1985 were obtained by the WDNR directly from Lake Michigan anglers. Fishes were measured in the field for total length, wrapped in aluminum foil, and frozen whole at -10 °C for shipment to the laboratory (Masnado 1987). Fish weight was determined either in the field or in the laboratory.

The majority of the samples were prepared and analyzed as fillets (skin-on) according to the U.S. Food and Drug Administration (FDA) *Pesticide Analytical Manual* (McMahon 1968). This included removal of the head, tail, fins, scales, viscera, and larger bones from each sample. A few of the larger fishes were prepared in the same way, only with the skin also removed (skin-off fillets). Many of the samples of smaller fish species consisted of two or more fish that were analyzed whole (i.e., the entire fish minus the viscera). In some cases smaller fishes were prepared as edible portions (head, tail, fins, scales, and viscera removed, but not bones or skin). Each sample was ground with a meat grinder, and a 118-ml subsample was used for analysis (Masnado 1987). The frozen fish tissues were thawed and ground with dry ice in a high-speed blender. After sublimation of the dry ice, 10 g of fish tissue was mixed with 60 g of anhydrous Na_2SO_4. This mixture was extracted in a 20-mm ID chromatographic column with 200 ml of dichloromethane at an elution rate of 5 ml per minute. The extract was concentrated to 5 ml under a stream of filtered air or by rotoevaporation. Five millilitres of 1:1 dichloromethane:cyclohexane was added.

For lipid determination, a 2-ml aliquot of solvent was put into a pretared aluminum weighing dish and evaporated under a stream of filtered air. The residue was weighed to the nearest 0.1 mg, and lipid concentration was determined using the following equation: percent lipid = (residue + dish weight - tare) x 100/sample weight.

Automated gel permeation chromatography was used to separate the PCBs from the lipids in the extract. A 60-g bed of SX-3 Biobeads gel resin was used in a solvent system of 1:1 cyclohexane in dichloromethane and packed into a glass column. The first 140 ml of eluate were discarded and the next 140 ml were retained. This eluate was concentrated to 5 ml under a stream of filtered air, then subjected to silica gel adsorption chromatography to separate the PCBs from most of the chlorinated pesticides. Silica gel columns were prepared by filling with solvent and the 5-ml eluate. The resulting eluate was collected for quantitation by gas chromatography. The peak height method of summing as many peaks as possible from the sample chromatogram by matching them with the corresponding peaks in the appropriate Aroclor PCB standard chromatogram was used for quantitation (Masnado 1987). The resulting PCB concentrations were reported as total PCBs.

Data Analysis

The data set was analyzed at the U.S. Army Engineer Waterways Experiment Station using descriptive statistics, correlation analysis, and analysis of variance (ANOVA) followed by Tukey's studentized range test for comparison of means. PCB concentration and lipid content data were transformed ($\log_{10}$ or arcsine-square root) when necessary to meet the ANOVA assumption of homogeneity of variances. For analysis of all species combined, heterogeneity of variances could not be corrected by a transformation, and ranked data were used in the ANOVA. Due to nonnormality of the data, correlations between PCB concentration and lipid content, total length, and weight were determined using Spearman's rank-order correlation coefficient.

3 Results and Discussion

Regional/Temporal Trends

The Wisconsin data set was divided into four regions (coastal, offshore, northern Green Bay, and southern Green Bay) for examination of regional trends (Figure 1). The coastal region included fishes collected primarily from bays, harbors, river mouths, and near urban areas. The offshore region included fishes collected from locations identified only by Lake Michigan grid numbers. Although some grid numbers encompassed nearshore areas, the locations given did not specify any cities or coastal features. Green Bay was divided into northern and southern sections along the line separating grid numbers 703-704 from grid numbers 803-804. Regional trends were examined for all fish species taken together; sample sizes were generally too small to warrant analysis of regional trends over time for individual species.

Mean PCB concentrations in fish tissues exhibited a general declining trend over the period 1978 to 1986 in each of the four regions (Table 1). Exceptionally high mean PCB concentrations occurred in fishes from the coastal region in 1978, due primarily to the influence of highly contaminated samples from the vicinity of Sheboygan Harbor. In subsequent years, mean PCB concentrations in samples from coastal locations (including Sheboygan Harbor) dropped to the same general range as those from the other three regions (Figure 2). During most years, mean PCB concentrations in fishes from the coastal region were higher than those in fishes taken offshore; likewise, mean PCB concentrations in fishes from southern Green Bay were higher than those in fishes from northern Green Bay. By 1986, the latest year for which data were available, mean PCB concentrations in fishes from offshore and from southern Green Bay had declined below the FDA action level of 2 µg/g wet weight in edible tissues, but remained above the FDA action level in fishes from the coastal region. No samples were obtained from northern Green Bay in 1986, but PCB concentrations in fishes taken from that region in 1985 still averaged slightly over 2 µg/g. Masnado (1987) also found elevated PCB concentrations in several species of salmonids from the Sheboygan River and from Green Bay in 1985, compared with PCB levels in salmonids from the remaining Wisconsin waters of Lake Michigan.

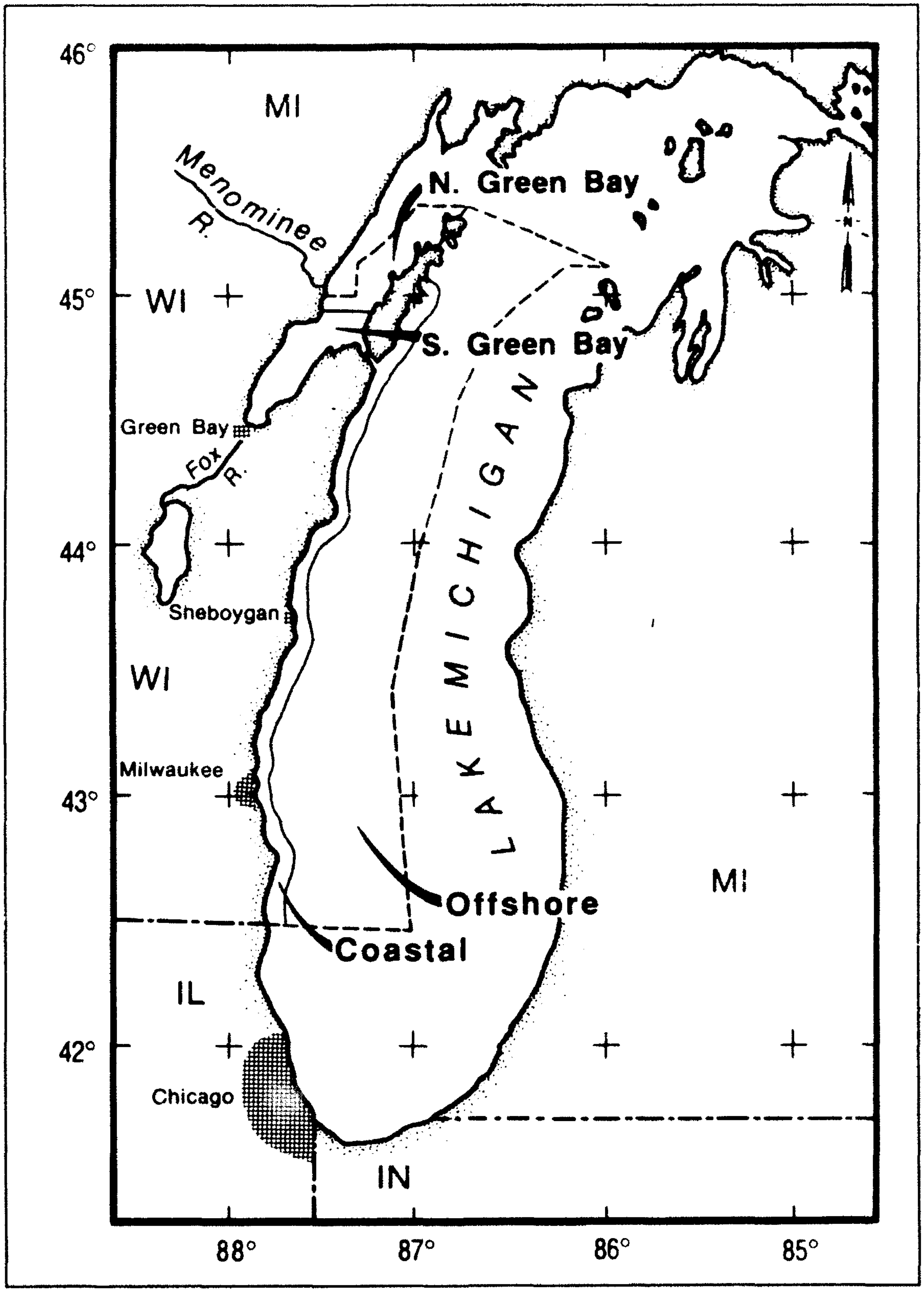

Figure 1. Map of study regions in Wisconsin waters of Lake Michigan

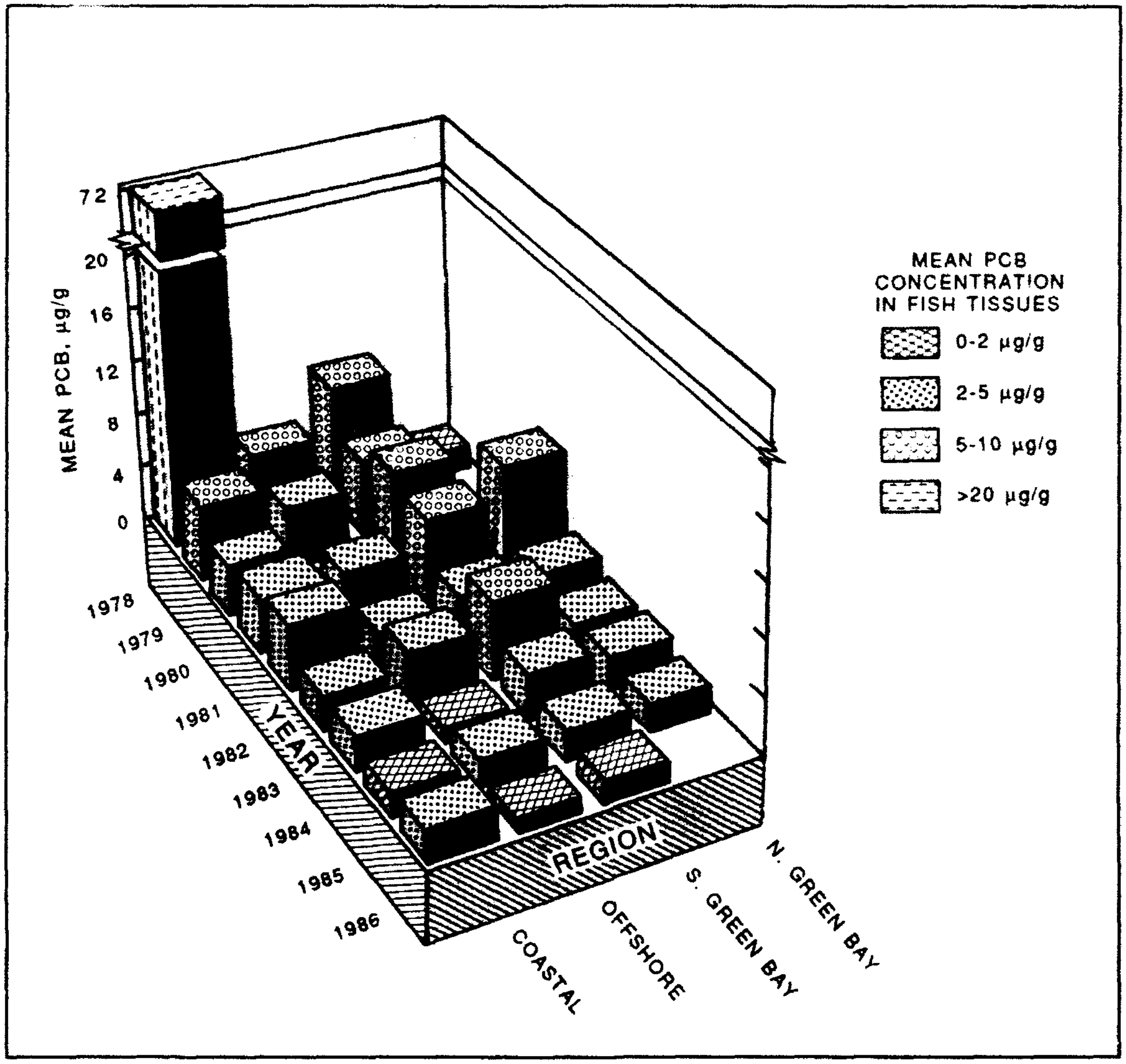

Figure 2. Regional trends in mean PCB concentrations in fishes from Wisconsin waters of Lake Michigan, 1978-1986

Species/Temporal Trends

Of 36 fish species in the Wisconsin data set, 13 were selected for examination of trends in PCB contamination (Table 2): brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*), bullheads (*Ictalurus* spp.), carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), lake trout (*Salvelinus namaycush*), northern pike (*Esox lucius*), rainbow trout (*Salmo gairdneri*), smallmouth bass (*Micropterus dolomieui*), walleye (*Stizostedion vitreum*), and yellow perch (*Perca flavescens*). These 13 were generally the species for which the largest number of samples were available over several years, and included primarily species of importance to the sport fishery.

Fishes had relatively high PCB body burdens in 1978, with mean concentrations over 90 μg/g wet weight in northern pike, walleye, and carp (Figure 3). After 1978, body burdens declined, with intermediate peaks in a few cases, to low levels by 1986. Two exceptions were channel catfish and carp, both of which still had moderately high PCB levels in the most recent years for which data were available. In 1986, coho salmon, chinook salmon, walleye, and channel catfish still had mean body burdens exceeding the FDA action level for PCBs. Among the salmonids, coho salmon and rainbow trout exhibited the least amount of PCB contamination over the 9-year time period (Figure 3a); among the other species, yellow perch were least contaminated (Figure 3b). PCB body burdens exceeding 20 μg/g (45 samples in 1978, 9 samples in later years) were found predominantly in carp and various other species from coastal locations, especially near the Sheboygan River. Some high concentrations also occurred in southern Green Bay (six samples), particularly near the Fox River. Only one sample from northern Green Bay (chinook salmon in 1981), and five from offshore (four lake trout in 1978 and one brown trout in 1981) exceeded 20 μg/g total PCBs.

Length, Weight, and Percent Lipid Correlations

PCB tissue concentrations tended to increase with total length, weight, and/or lipid content in each of the 13 fish species except brook trout (Table 3). PCB levels were significantly positively correlated ($P < 0.05$) with both fish weight and fish length in brown trout, carp, channel catfish, chinook salmon, coho salmon, lake trout, and all 36 species combined. Lipid content and PCB concentrations were significantly correlated in each of the 13 species except brook trout and channel catfish. Most of these significant correlations were fairly weak. PCB concentrations were strongly correlated ($r > 0.7$) with weight and length only in chinook salmon and lake trout, and with lipid content in lake trout, smallmouth bass, walleye, and yellow perch.

Partitioning of hydrophobic compounds such as PCBs into the organic fraction of environmental compartments, including the lipid fraction of organisms, is well established (Jensen et al. 1969; Riley and Wahby 1977; Könemann and van Leeuwen 1980; Geyer et al. 1982; Mackay 1982; McFarland and Clarke 1986; Clarke, McFarland, and Dorkin 1988). Thus, a positive correlation might be expected between PCB concentrations and lipid content of fishes given a fairly uniform contaminant exposure source. Schneider (1982) noted a highly significant correlation ($r = 0.99$) between lipid content and wet-weight PCB concentrations in cod (livers and fillets) and in some of their prey organisms from the Baltic Sea. Camanzo et al. (1987) also noted a positive correlation between lipid content and PCB concentrations in whole-fish samples, especially carp, taken from Lake Michigan tributaries and embayments in 1983. The relatively weak correlations observed between tissue PCB levels and percent lipid in most of the Lake Michigan fish species in the present study may be indicative of

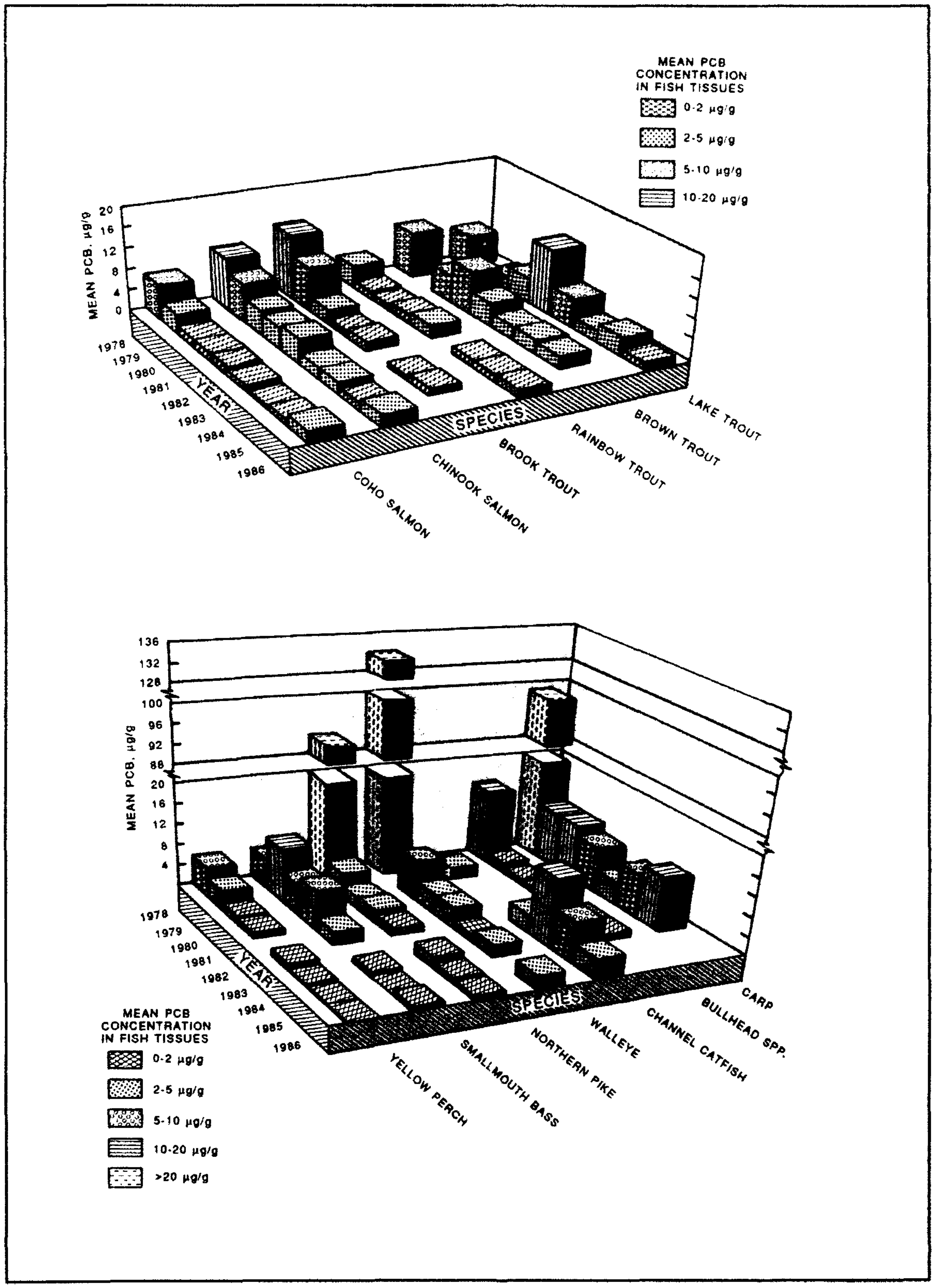

Figure 3. Trends in mean PCB concentrations in 13 fish species from Wisconsin waters of Lake Michigan, 1978-1986

widely varying contaminant concentrations in the sediments, water, and food sources to which these fishes were exposed.

Significant correlations between PCB concentrations and fish weight or length may reflect increased bioaccumulation with age, biomagnification from lower trophic levels, or an increase in lipid content with age. Correlations between percent lipid and weight or length were weak to moderate ($r < 0.7$) in most of the Lake Michigan fishes, and were statistically significant ($P < 0.05$) only in brook trout, brown trout, carp, coho salmon, lake trout, and rainbow trout. This suggests that positive correlations between PCB concentrations and weight or length are probably not attributable solely to increasing lipid content with age but to other factors as well, such as varying degrees of contaminant exposure and changes in diet with age. For example, lake trout under 2 years old consume invertebrates, whereas older lake trout are primarily piscivorous (Thomann and Connolly 1984).

Changes in contaminant body burdens over the lifetime of a fish can be affected by spawning. PCBs can accumulate in the eggs of mature females (Black, Phelps, and Lapan 1988), with subsequent contaminant depuration due to spawning (Guiney et al. 1979). However, the net result could be either a decrease or an increase in the PCB tissue concentrations of the females, depending upon the species, the percent egg weight of body weight, and the concentrations of PCBs in the eggs relative to the remaining tissues (Niimi 1983).

Differences in PCB body burdens among fish species could be attributed to trophic level differences either in biomagnification or in exposure to contaminant sources such as organic carbon-rich or fine-grained sediments. Schneider (1982) observed a decrease in lipid-weight PCB concentrations with increasing trophic levels, in agreement with the conclusions of other investigators that accumulation of organochlorines in aquatic organisms will occur primarily from exposure to sediments and particulate matter rather than through biomagnification from food sources (Crump-Wiesner, Feltz, and Yates 1974; Harvey 1974; Sayler and Colwell 1976; Pavlou and Dexter 1979; Osterroht and Smetacek 1980). Likewise, Camanzo et al. (1987) found higher PCB concentrations in bottom-feeding fishes such as carp, than in top predators like northern pike, from Lake Michigan. However, other recent studies emphasize contaminated food as a major source of PCB residues in fish (Connolly and Pedersen 1988; Oliver and Niimi 1988; van der Oost, Heida, and Opperhuizen 1988). Based on the work of Weininger (1978), Thomann and Connolly (1984) modeled the Lake Michigan lake trout food chain and found that more than 99 percent of the PCBs in lake trout resulted from biomagnification rather than from lake water exposure. In the present study, highest overall mean PCB concentrations occurred in carp, northern pike, and walleye, followed by channel catfish, bullheads, lake trout, and smallmouth bass. These species include both bottom feeders (carp, channel catfish, bullheads), which would have maximum exposure to sediments as a source of PCBs, and top predators (northern pike, walleye, smallmouth bass), which would probably accumulate PCBs primarily from ingestion of prey organisms. Thus, although sediments are likely an important source of contaminants particularly to bottom-feeding species, the role of biomagnification may be considerable for many species.

Influence of Sample Type

Mean PCB concentrations were compared among the four types of samples included in this study (whole fish, fillets, skin-off fillets, and edible portion). For all 36 species combined, PCB concentrations (ranked data) were significantly higher in whole-fish samples than in fillets and edible portions but not skin-off fillets (ANOVA $F = 25.68$, $P < 0.0001$, $n = 1908$). Among the individual species, PCB concentrations were significantly higher in whole fish than in one or more types of fillet from coho salmon, northern pike, rainbow trout, smallmouth bass, walleye, and yellow perch. In the other seven species, PCB concentrations did not differ significantly among sample types. However, widely differing sample sizes and variances among the sample types reduce the power of such statistical comparisons. Mean PCB concentrations and percent lipid for the different sample types are given in Table 4.

The higher PCB concentrations in whole fish were most likely reflective of the higher lipid content in whole-fish preparations than in fillets. In chinook salmon, northern pike, smallmouth bass, walleye, yellow perch, and all species combined, percent lipid was significantly higher in whole-fish samples than in any type of fillet. Nevertheless, the whole-fish samples (and also edible portions) were generally prepared from smaller individuals than were the fillets and skin-off fillets. We observed in the previous section that PCB concentrations tended to increase with fish size in nearly all species; thus the influence of fish size would tend to confound the influence of lipid content on PCB concentration differences among the sample types. An additional factor that influenced differences in PCB concentrations (but not lipid content) among sample types in northern pike and walleye was the presence of several extremely contaminated samples of these two species, taken in 1978 from Sheboygan River. These highly contaminated samples were analyzed as whole fish.

Limitations of Total PCB Analyses

PCB concentrations in the samples used in this study were quantitated as total PCBs based on Aroclor standards. Such quantitations, while providing a measure of contamination, give no information as to the presence or proportions of the relatively few potentially toxic congeners among the 209 theoretically possible PCB congeners (Bunyan and Page 1978). Moreover, due to degradation and differential affinities of congeners for various environmental compartments, PCBs in environmental samples seldom correspond well to Aroclor standards (Duinker and Hillebrand 1983; Duinker, Hillebrand, and Boon 1983; Bush et al. 1985; McFarland, Clarke, and Gibson 1986). Thirty-six PCB congeners of greatest concern due to frequent environmental occurrence, abundance in environmental samples, and/or potential for toxicity are identified in McFarland and Clarke (1989) and Clarke, McFarland, and Pierce (1989).

A number of recent investigations have quantitated specific PCB congeners in Great Lakes fishes. Hesselberg and Seelye (1982) analyzed 29 PCB congeners in lake trout and walleye collected from the Great Lakes in 1977, but did not report concentrations. Cleland, Oliver, and Sonstegard (1988) measured 46 congeners in coho salmon from Lakes Michigan and Ontario in 1982. They found individual congener concentrations up to 0.26 μg/g, and total PCB concentrations of 0.7 μg/g in Lake Michigan fishes and 2.3 μg/g in Lake Ontario fishes. Huckins et al. (1988) detected some of the more toxic PCB congeners in several fish species from Waukegan Harbor, Lake Michigan, at concentrations up to 0.48 μg/g. Maack and Sonzogni (1988) analyzed 95 congeners in eight species of fishes from Wisconsin waters, including Lake Michigan, collected in 1986-87, but did not report individual congener concentrations. Total PCB concentrations ranged from 0.07 to 7.0 μg/g. Swackhamer and Hites (1988) reported lipid-weight concentrations up to 1.6 μg/g for 19 PCB congeners in lake trout and whitefish (*Coregonus culpeaformis neohantoniensus*) collected from an inland lake on Isle Royale, an island in Lake Superior (collection date unspecified). Niimi and Oliver (1989a) measured eight toxic PCB congeners in four species of Lake Ontario salmonids at concentrations up to 0.4 μg/g. They concluded that these levels were potentially 5 to 10 times more toxic to mammals consuming the fishes than the much lower levels of highly toxic dioxins or furans found in the same fishes. In a second paper (Niimi and Oliver 1989b), they reported concentrations of 92 PCB congeners in these same fishes. Individual congener concentrations ranged from undetected to 1.08 μg/g, with total PCB concentrations up to 10 μg/g.

Although all 209 PCB congeners have been synthesized and can be quantitated in environmental samples (Mullin et al. 1984; Safe, Safe, and Mullin 1985), such analyses are costly and technically difficult. Even analyses of a limited number of specific congeners are not routinely performed when assessing PCB content of environmental samples, and the interpretation of such data is complex. While regulatory evaluations of PCB-contaminated sediments for dredging and disposal activities may remain controversial in their ability to determine potential toxic consequences to aquatic biota, specific-congener analyses could assist in providing more accurate assessments, particularly as specific-congener data are accumulated and interpreted.

4 Conclusions

PCB concentration data from fishes collected in the Wisconsin waters of Lake Michigan clearly indicate declining PCB levels during recent years, particularly from the high concentrations observed in the late 1970s and early 1980s. By 1985-86, mean PCB concentrations in fishes from offshore waters of Wisconsin and from southern Green Bay had declined below the FDA action level of 2 µg/g, whereas mean concentrations in fishes from coastal waters and northern Green Bay remained in the 2- to 5-µg/g range. Among the 13 species considered in this study, brook trout, bullheads, lake trout, northern pike, rainbow trout, smallmouth bass, and yellow perch averaged less than 2 µg/g PCBs by 1986. Mean PCB concentrations in brown trout, channel catfish, chinook salmon, coho salmon, and walleye were still in the 2- to 5-µg/g range during the most recent year for which data were available (1985 or 1986). Carp, which were last sampled in 1984, had even higher mean PCB concentrations (11 µg/g). Other investigators (Baumann and Whittle 1988) have documented declining concentrations of organic contaminants, including PCBs, in Great Lakes biota from the late 1970s through the early 1980s, followed by fluctuating lower levels in more recent years.

Although fish body burdens of PCBs may continue to decline due to ongoing reductions in contaminant input to the Great Lakes, health hazards to biota may remain. Human health consequences from consumption of Lake Michigan fishes have been documented (Swain 1988), but the extent of the hazard remains uncertain. The Great Lakes states have attempted to minimize human exposure by issuing fish consumption advisories, but these advisories were developed using a variety of methods and trigger levels, and are inconsistent from state to state (Foran and VanderPloeg 1989). Clark, Fink, and DeVault (1987) discussed shortcomings of basing fish consumption advisories on FDA contaminant action levels, and recommended a cancer-risk assessment approach instead. For PCBs, the problem is compounded because quantitations as total PCBs (or as Aroclor equivalents) cannot identify the presence or concentrations of the relatively few potentially toxic PCB congeners.

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Table 1
Mean Annual Total PCB Concentrations (μg/g Wet Weight) in Samples of 36 Fish Species Collected from Coastal and Offshore Wisconsin Waters of Lake Michigan, and from Southern and Northern Green Bay

	Year								
Region	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**
Coastal	71.24[1] (12.55) *105*	5.25 (1.29) *29*	3.95 (0.49) *77*	4.06 (1.04) *52*	4.84 (0.53) *79*	2.43 (0.24) *64*	2.63 (0.46) *100*	1.73 (0.12) *200*	2.25 (0.17) *68*
Offshore	5.13 (0.87) *61*	3.52 (1.33) *6*		3.97 (1.43) *23*	2.38 (0.63) *12*	3.77 (0.59) *33*	1.27 (0.12) *151*	2.04 (0.11) *421*	0.89 (0.09) *27*
Southern Green Bay	8.37 (1.24) *26*	5.57 (1.46) *11*	7.24 (1.30) *15*	5.75 (0.77) *36*	3.32 (0.65) *15*	5.03 (1.62) *23*	3.12 (0.47) *52*	2.15 (0.19) *68*	1.53 (0.20) *25*
Northern Green Bay	1.74 (0.29) *14*			8.06 (3.82) *9*	3.22 (0.95) *5*	2.31 (0.86) *10*	2.64 (0.39) *10*	2.06 (0.09) *143*	

[1] Each annual mean followed by standard error in parentheses followed by sample size in italics.

Table 2
Mean Annual PCB Concentrations (µg/g Wet Weight) in 13 Selected Fish Species and in All 36 Fish Species Combined from Wisconsin Waters of Lake Michigan, 1978-1986

	Year								
Species	**1978**	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**
Brook trout	12.53[1] (2.39) *6*	8.30 *1*	2.42 (0.30) *6*	1.02 (1.08) *2*	1.64 (1.06) *4*		0.73 (0.10) *21*	1.28 (0.13) *52*	
Brown trout	8.90 (1.79) *4*		5.06 (1.01) *7*	8.35 (5.16) *6*	4.49 (0.82) *9*	2.55 0.61 *6*	2.79 (0.23) *36*	2.27 (0.09) *188*	
Bullhead spp.	14.75 (7.47) *6*	1.95 (0.45) *5*	1.11 (0.29) *2*	1.08 (0.13) *2*		0.96 (0.30) *6*	1.08 (0.30) *4*		
Carp	97.57 (25.44) *47*	11.57 (3.57) *8*	11.51 (2.27) *11*	9.62 (2.21) *24*	4.50 (0.86) *9*	8.95 (2.78) *12*	10.98 (2.64) *12*		
Channel catfish		2.37 (1.84) *2*				3.55 (0.35) *2*	13.73 (3.24) *3*	7.97 (4.02) *3*	4.06 (0.64) *7*
Chinook salmon	10.03 (0.62) *17*	7.20 *1*	4.51 (0.31) *20*	3.96 (0.75) *50*	4.60 (0.41) *41*	2.05 (0.17) *33*	2.18 (0.17) *41*	1.26 (0.07) *209*	2.27 (0.15) *40*
Coho salmon	6.70 (0.87) *5*	3.58 (1.06) *5*	1.73 (0.23) *10*	1.71 (0.33) *7*	1.94 (0.36) *20*	1.51 (0.42) *4*	0.66 (0.10) *29*	0.89 (0.07) *69*	2.22 (0.39) *14*
Lake trout	6.61 (1.45) *34*		2.58 (0.51) *7*	4.93 (2.84) *3*	13.02 (2.22) *10*	5.77 (0.65) *24*	2.27 (0.35) *46*	3.72 (0.26) *148*	1.62 (0.30) *5*
Northern pike	91.18 (34.04) *5*	4.20 (1.01) *4*	2.03 (0.30) *3*	2.22 (0.35) *6*	1.22 (0.34) *4*		1.85 (0.93) *7*	0.95 (0.05) *2*	0.71 (0.19) *5*
Rainbow trout	4.40 (1.13) *7*	1.55 (0.15) *2*	1.27 (0.27) *9*	1.97 (0.15) *3*	2.45 (1.30) *6*		1.44 (0.41) *21*	1.50 (0.20) *66*	1.56 (0.21) *16*
Smallmouth bass	5.70 (3.10) *2*	10.45 (8.05) *2*	6.05 (1.05) *2*	7.50 *1*	2.50 *1*		0.86 (0.52) *3*	0.30 *1*	0.76 (0.15) *5*
Walleye	133.00 (108.00) *2*		7.72 (1.31) *6*	3.63 (0.64) *10*	3.71 *1*	1.26 (0.43) *9*	2.28 (1.22) *3*		2.64 (1.10) *3*
Yellow perch	5.60 *1*	3.60 *1*	1.26 (0.35) *2*	1.20 (0.20) *2*		1.14 (0.26) *10*	0.38 (0.06) *15*	0.21 (0.01) *3*	0.20 (0.00) *2*
All 36 species combined	39.01 (6.79) *206*	5.10 (0.90) *46*	4.48 (0.48) *92*	4.85 (0.64) *120*	4.30 (0.40) *111*	3.23 (0.36) *129*	2.05 (0.18) *313*	1.98 (0.07) *8.32*	1.80 (0.12) *120*

[1] *Each annual mean followed by standard error in parentheses followed by sample size in italics.*

Table 3
Mean Weight, Length, and Percent Lipid of 13 Selected Fish Species and All 36 Fish Species Combined from Wisconsin Waters of Lake Michigan, 1978-1986; and Correlations of These Parameters with Tissue PCB Concentrations

Species	Weight, kg	Length, cm	Lipid Content, %	Correlation with (PCB)		
				Weight	Length	% Lipid
Brook trout	0.54[1] (0.03) *85*	33.91[1] (0.66) *92*	4.71[1] (0.25) *92*	0.08[2] 0.4608 *85*	0.11[2] 0.3025 *92*	0.09[2] 0.3698 *92*
Brown trout	2.16 (0.08) *252*	50.11 (0.69) *256*	10.93 (0.32) *256*	0.31 * 0.0001 *252*	0.32 * 0.0001 *256*	0.16 * 0.0128 *256*
Bullhead spp.	0.32 (0.13) *16*	21.56 (0.63) *25*	2.36 (0.34) *25*	0.03 0.9067 *16*	-0.11 0.6112 *25*	0.49 * 0.0137 *25*
Carp	2.93 (0.23) *72*	55.87 (1.04) *123*	12.08 (0.59) *123*	0.39 * 0.0007 *72*	0.29 * 0.0013 *123*	0.28 * 0.0018 *123*
Channel catfish	1.56 (0.28) *16*	49.98 (2.83) *17*	8.93 (1.09) *17*	0.58 * 0.0187 *16*	0.59 * 0.0118 *17*	0.16 0.5348 *17*
Chinook salmon	4.38 (0.14) *434*	72.21 (0.89) *452*	3.77 (0.15) *452*	0.77 * 0.0001 *434*	0.74 * 0.001 *452*	0.26 * 0.0001 *452*
Coho salmon	2.13 (0.11) *153*	53.64 (1.19) *163*	3.89 (0.17) *163*	0.31 * 0.0001 *153*	0.21 * 0.0074 *163*	0.32 * 0.0001 *163*
Lake trout	2.64 (0.11) *243*	60.80 (1.01) *277*	13.33 (0.37) *277*	0.92 * 0.0001 *243*	0.85 * 0.0001 *277*	0.75 * 0.0001 *277*
Northern pike	2.20 (0.24) *28*	63.95 (2.26) *36*	1.98 (0.23) *36*	-0.05 0.7840 *28*	-0.16 0.3446 *36*	0.62 * 0.0001 *36*
Rainbow trout	1.84 (0.13) *121*	49.45 (1.33) *130*	6.80 (0.32) *130*	-0.03 0.7317 *121*	-0.01 0.9015 *130*	0.20 * 0.0210 *130*
Smallmouth bass	0.49 (0.09) *14*	30.45 (1.18) *17*	3.05 (0.60) *17*	0.18 0.5380 *14*	0.22 0.4037 *17*	0.90 * 0.0001 *17*
Walleye	1.37 (0.16) *32*	47.13 (1.77) *33*	5.84 (0.63) *34*	0.33 0.0654 *32*	0.16 0.3645 *33*	0.75 * 0.0001 *34*
Yellow perch	0.19 (0.02) *34*	23.06 (0.74) *36*	2.04 (0.34) *35*	0.10 0.5845 *34*	-0.26 0.1231 *36*	0.82 * 0.0001 *35*
All 36 species combined	2.42 (0.05) *1733*	52.91 (0.48) *1967*	7.66 (0.14) *1968*	0.51 * 0.0001 *1733*	0.38 * 0.0001 *1967*	0.41 * 0.0001 *1968*

[1] Each annual mean followed by standard error in parentheses followed by sample size in italics.
[2] Correlation coefficient (Spearman's rank order) followed by probability P under H_0: $\rho = 0$ followed by sample size in italics; * indicates significant correlations ($P < 0.05$).

Table 4
Mean PCB Concentrations (µg/g Wet Weight) and Percent Lipid in Different Sample Types of Fishes from Wisconsin Waters of Lake Michigan, 1978-1986

	Whole Fish		Edible Portion		Fillet		Skin-Off Fillet	
Species	PCB	% Lipid	PCB	% Lipid	PCB	% Lipid	PCB	% Lipid
Brook trout	1.70[1] *1*	7.00 *1*	0.49 (0.29) *2*	3.80 (1.20) *2*	2.08 (0.36) *89*	4.71 (0.26) *89*		
Brown trout	3.77 (0.61) *3*	14.17 (0.44) *3*	3.65 (0.15) *2*	3.95 (1.35) *2*	2.73 (0.17) *251*	10.95 (0.32) *251*		
Bullhead spp.	10.92 (6.00) *8*	2.55 (0.55) *8*			2.75 (0.35) *2*	2.30 (0.60) *2*	1.01 (0.21) *10*	1.26 (0.20) *10*
Carp	39.93 (11.48) *60*	11.33 (0.77) *60*			60.19 (23.35) *46*	13.39 (1.15) *46*		
Channel catfish	6.80 *1*	15.00 *1*					6.70 (1.48) *14*	9.37 (1.08) *14*
Chinook salmon	4.02 (0.81) *12*	6.58 (0.87) *12*			2.56 (0.14) *417*	3.76 (0.16) *417*	2.13 (0.17) *23*	2.53 (0.59) *23*
Coho salmon	2.49 (0.32) *15*	3.59 (0.36) *15*			1.37 (0.13) *145*	3.94 (0.19) *145*	0.31 (0.05) *3*	3.13 (0.79) *3*
Lake trout	4.79 (1.19) *7*	12.94 (1.85) *7*	0.80 *1*	2.70 *1*	4.29 (0.29) *269*	13.38 (0.38) *269*		
Northern pike	74.47 (31.44) *6*	3.07 (0.33) *6*			1.49 (0.28) *25*	1.34 (0.15) *25*		
Rainbow trout	4.70 (2.42) *3*	3.00 (0.86) *3*	2.45 (0.85) *2*	3.90 (0.80) *2*	1.61 (0.15) *125*	6.94 (0.32) *125*		
Smallmouth bass	5.70 (3.10) *2*	6.65 (1.85) *2*			1.38 (0.66) *10*	1.20 (0.17) *10*		
Walleye	42.52 (33.22) *7*	11.14 (0.71) *7*			2.52 (0.42) *23*	4.08 (0.49) *23*		
Yellow perch	2.15 (0.54) *8*	5.08 (0.51) *8*			0.42 (0.05) *27*	0.99 (0.12) *26*		
All 36 species combined	22.66 (3.90) *235*	9.41 (0.44) *235*	1.29 (0.26) *16*	3.44 (0.26) *16*	4.26 (0.71) *1607*	7.57 (0.15) *1606*	3.08 (0.53) *50*	4.23 (0.61) *50*

[1] Each annual mean followed by standard error in parentheses followed by sample size in italics.

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